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Water use opportunities and conflicts in a small watershed—a case study

Shaligram Pokharel*

School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639 798, Singapore

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Abstract

Water available in small watersheds primarily serves household and irrigation needs of the local population. For economical use of water, correct understanding of water availability is necessary mainly because the consequences of such plans are immediate and they could impact the livelihood of people around the watershed. In this paper, a post project case is presented to highlight the opportunities and conflicts on water use in a small watershed. Simulation study is done to show the impact of water regulation for irrigation and power generation. Based on the case study, a few recommendations have been made on water regulation policy to avoid water use conflicts in the study area.

Keywords: Small watersheds; Irrigation; Power generation; Water use conflict

Contents

*Tel.: +65 6790 4272; fax: +65 6791 1859.
E-mail address: mspokharel@ntu.edu.sg.

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1. Introduction

The uses of water are dependent on water availability, which in turn is seasonal often varying by more than 10 times between dry and wet seasons [1]. In small watersheds, water availability may not be abundant to consider all possible uses such as household uses, irrigation, recreation and hydropower generation.

The household demand for water is continuous throughout the year. However, water demand for irrigation and power generation could be seasonal. While in wet season, the demand for irrigation water is almost insignificant; its demand is higher in the dry season thus creating an imbalance in water supply and demand. However, water demand for irrigation does not only depend on the season but also on the cropping pattern and soil condition of the area. The application (or field) efficiency of irrigation water depends on the soil condition of the area [2]. On the other hand, as the demand for electricity could change, for example, between the summer and winter periods, so might be the water requirements for power generation. Depending upon the electricity consumption pattern in the local area, there might also be daily changes in water requirements. Therefore, planners facing such situations attempt to regulate water distribution.

Small dams are usually considered as a mechanism to regulate water distribution in different seasons. In small watersheds, however, such dams may not be able to supply total water demand throughout the year. While larger dams may submerge precious agricultural land upstream, smaller dams may not be able to contain enough water to regulate it throughout the year. Also, the regulated water can even bring water use conflicts if they are used as a competing source for downstream uses such as irrigation and power generation. Therefore, a careful planning of water use in small watershed is more crucial as they meet immediate needs of local people and have impact on their livelihood.

It should be noted that irrigation and power generation may not compete for water when they are designed as a cascaded system with power generation facility in the upstream. However, this paper presents a post-project case where water demand for irrigation and power generation are not cascaded and due to the currently adopted water regulation policy, water use conflicts have become prominent.

2. Study area

The location of watershed is in the western Nepal, as shown in Fig. 1. The study area (adjoining Pokhara town) is about 200 km west of Kathmandu. In Fig. 2, the detail feature of the study area is shown. The watershed used for storage and regulation of water covers about 120 km^2 and has an average slope ranging between 15° and 30° [3]. The hydrological

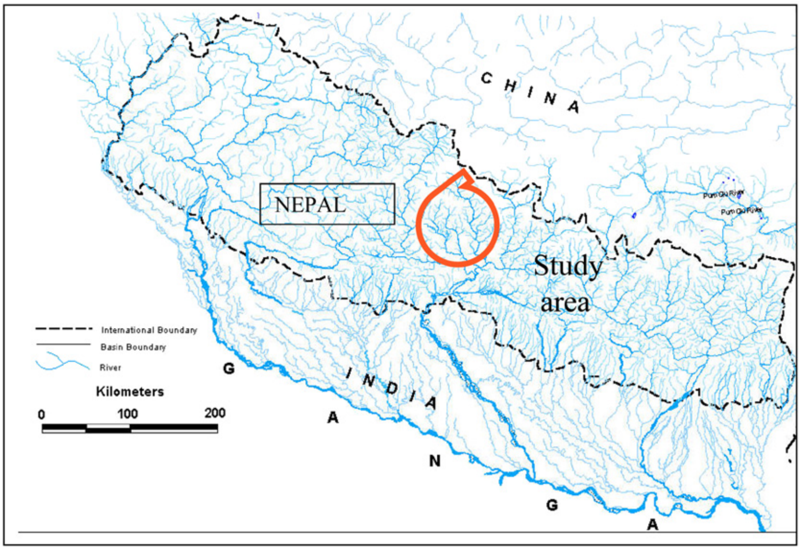

Fig. 1. Study area.

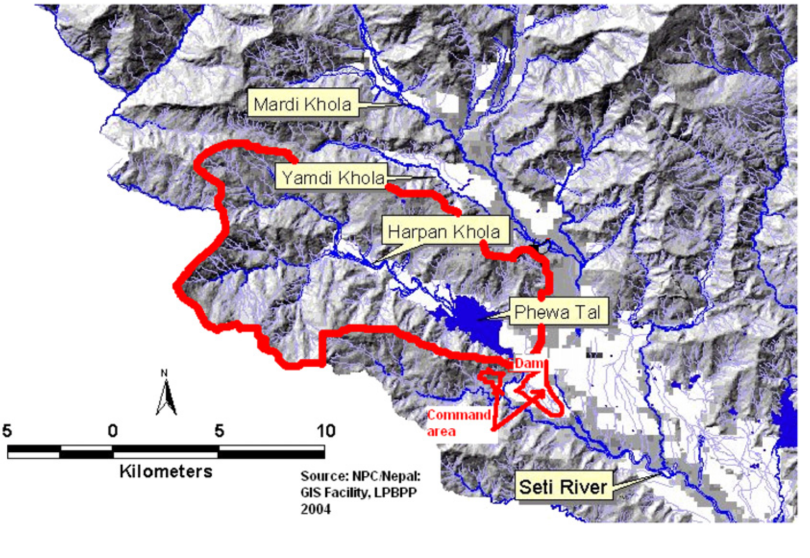

Fig. 2. Phewa watershed (*Source*: National Planning Commission/Nepal).

data shows that the watershed area receives between 3500 and 5000 mm of rainfall annually, most of which is received between June and September.

Harpan *Khola* (*Khola* = stream) drains the watershed into Phewa *Tal* (lake or reservoir) at the end of the watershed (Fig. 2). The maximum depth of the lake is estimated at 20 m [4] to 24 m [5]. Although, the average flow of Harpan Khola is 9 cum/s, due to intense

rainfall for a few months, smaller size of the watershed and steep slope of hills, the ratio of minimum to maximum flow in the stream is about 18.

A concrete dam was constructed in 1967 at the end of the lake to raise the water level but the dam collapsed in 1977. The current dam is 11.5-metre high (with flood levels at 795.7 m asl) and was built between1978 and 1982 (at a cost of about US$ 5 million at that time). The dam has four gates (each 5.7 m width $\times$ 5.8 m height) to regulate water. The data found in literature on the area and volume of Phewa is confusing. While Rai [5] mentions the area and the volume as 5.23 km^2 and 39.32 million m^3, Ross and Gilbert [4] mention that to be 4.35 km^2 and 37.76 m^3. However, official records obtained from the Department of Irrigation (personal communications) shows that the dead storage capacity of the reservoir is 40 million m^3 with maximum active storage of 13 million m^3. The canal intake is at 791.20 m (elevation). Since correlation of data obtained from various studies are difficult, it is assumed that the dead storage is attained at 791.2 m and the maximum active storage is obtained at 794.7 m (which is mentioned as the maximum poundage level). The normal operating level of dam is at 793.7 m (as obtained from the Department of Irrigation records). The total storage at this level is estimated as 45.6 million m^3. The records show that at the normal operating level, the area of the reservoir is 5.8 km^2. These official records are used for further analysis.

Water outflow from the dam is carried through two canals, one on each side of the dam (as shown in Fig. 3). The outflow from the left bank canal is used for irrigation and power whereas that from the right bank is used for irrigation only. The capacity of left bank canal is 9 m^3/s and that of right canal is 1 m^3/s.

The left bank canal system covers irrigation command area of 211 ha and the right bank canal system covers another 45 ha. Although, it is often mentioned that the potential irrigable land in the study area is 320 ha, DOI [6] study mentions that only 256 ha the study area can be irrigated.

There are no studies in the command area to show the quantum rise in the productivity of the land, although the general perception is that the productivity with irrigation increases due to the potential of increased cropping intensity and the possibility to use

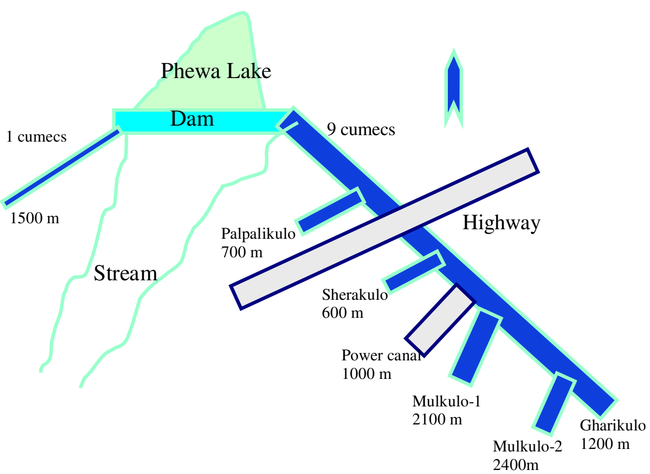

Fig. 3. Layout of irrigation and power canals (layout is not to scale).

more improved seeds [7]. Compared to traditional farming practices, land productivity with irrigation and improved seeds could increase by more than two folds.

Phewa Tal is also a major tourist attraction and it contributes to the local economy substantially. The damming of water has made this possible. In general, the opportunity of regulated water in this watershed is higher compared to unregulated water use.

Various crops are grown in the watershed area [6] but the two major crops in the area are paddy (summer crop) and wheat (winter crop). If irrigated water can be supplied then cropping intensity can be increased to three crops a year by growing winter paddy crop (called early paddy).

The crop cycles and water requirements for the major crops grown in the study area are given in Table 1. The irrigation sector master plan has provided the net crop water requirement for the study area. The water diversion required from the dam is based on 60% field efficiency, 70% distribution efficiency and 70% canal efficiency. For accounting purpose, it is assumed that crops are harvested or planted in the middle of the month. It can be seen from the table that if water from the reservoir is released only for irrigation, then this would be a sustainable operation as the average water demand is always less than the average flow received into the reservoir.

A 1 MW hydropower station was installed in 1982 to supply electricity for local use. The generating station has a designed discharge of 0.5 m^3/s for each turbine unit of 250 kW and a gross head of about 75 m. However, due to poor canal efficiency, this hydropower station requires about 2.82 cumecs of water for electricity generation. At 80% efficiency of turbines, the potential annual power generation from these turbines is about 6.0 giga Watt hours (GWh). The Electricity Authority currently purchases power from small hydropower utilities at Rs 3 (US $ 0.04) per Kilo Watt hours (KWh). That means, the value of this generation is over US $ 240,000. With the expansion of the national electricity grid for electricity distribution in the study area, this station is now connected to the national grid for uplink.

Table 1
Water demand for various crops throughout the year

Month	Average monthly reservoir inflow (m^3/s)	Crop season	Water demand (mm)	Required diversion from reservoir (m^3/s)
January	1.53	Wheat	70	0.23
February	1.35	Wheat–early paddy	281	1.01
March	1.30	Early paddy	350	1.14
April	1.24	Early paddy	347	1.16
May	1.68	Early paddy	139	0.45
June	5.72	Early paddy–main paddy	2	0.006
July	22.65	Main paddy	211	0.68
August	20.32	Main paddy	0	0
September	16.30	Main paddy	0	0
October	6.68	Main paddy	183	0.59
November	2.66	Main paddy–wheat	246	0.83
December	1.79	Wheat	53	0.17

Data source for inflow, cropping season and water demand: [6].

From Table 1, it can be inferred that when water requirements for both power generation and irrigation are considered, there are water use conflicts in the study area. This decreases the expected benefits to farmers and electricity utility. The current dam operation policy is to release water for hydropower generation for 9 months and to release water for irrigation throughout the year. Analysis on the impact of current operation policy is done here to provide recommendation for better operation policy so that additional benefits can be obtained from power generation as well. It is to note that this lake (or reservoir) primarily caters to the recreational purposes. However, even with water at the dead storage level, the recreation activity is not affected.

3. Water use analysis

Due to the absence of data on daily or monthly water flow from the reservoir, a simulation study was carried out. Various scenarios are developed to understand the water balance situation in the reservoir.

3.1. Simulation with normal operating level

To be consistent with the current reservoir operating policy, the normal operating level of 45.6 million m^3 (793.7 m) was considered first (dead storage is maintained at 40 million m^3 during the analysis). Average monthly flow based on 21 years average inflow as obtained from the Department of Irrigation records is given in Table 1. The average of this time series data is expected to give a fair approximation of the inflow received by the reservoir. Simulation shows that if the maximum use of both irrigation and power generation is considered, then water would not be sufficient to meet the demands from the middle of December to the middle of June. That means, water cannot be released from the reservoir for 6 months. With this operation policy the maximum power generation would be about 2.9 GWh. This policy, therefore, clearly creates disillusion of having irrigation water for increasing crop intensity. The farmers do not get additional benefit to increase crop intensity during the dry periods. Therefore, this creates a water use conflict for power generation and irrigation. To avoid this situation, further analysis was done by allowing maximum poundage of 53 million m^3 in the reservoir.

3.2. Simulation with maximum poundage level

The result of the simulation study given in Fig. 4 shows that even with the policy of retaining maximum storage to 53 million m^3 during the wet season, dam outflow cannot meet both power and irrigation demand throughout the year. However, this policy would provide additional water for irrigation and power for 2 more months compared to 6 months at average water level. The figure also shows that there would be high spillage during the wet season, however. The analysis shows that the maximum power generation in this case would be about 4.1 GWh.

The current water release policy of releasing water for nine months (from June to February) for power generation and releasing irrigation water throughout the year is not a viable option even with maximum poundage. However, if power generation is stopped from February to April, the irrigation water demand during those periods can be met by the reservoir. This will generate about 5.3 GWh of power. The shift in operating months

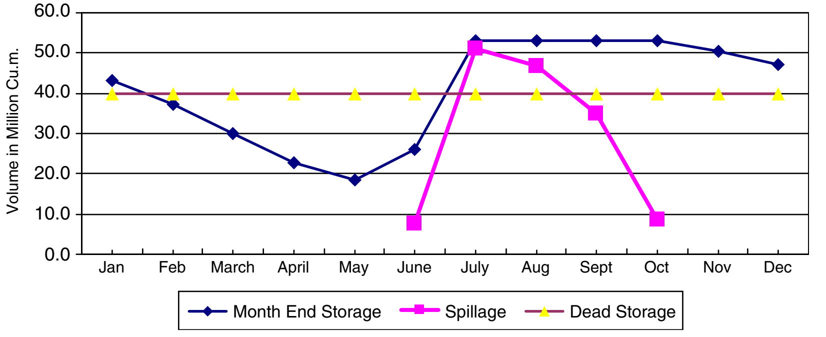

Fig. 4. Profile of water storage in dam based on design.

would however depend upon the timing of monsoon. The field engineer at the study site validated the consequences of water release and arising conflicts and further mentioned that hydropower generation might have to be stopped for a longer period based on the inflow to the reservoir.

The above analysis shows that water demand for irrigation and electricity generation cannot be met simultaneously even when the active storage is at the maximum level. The records also show that the power generation in the past has been about 2.1 GWh (35% of capacity) for several years. The complete shut down of generating stations for more than 4 months is also not uncommon. Recently, the power station has been shut down for 3 years due to water shortage and other technical problems. Therefore, to understand the impact of dam operating policy on hydropower generation, with the main objective of providing water for irrigation throughout the year and maximizing power output, four main simulation scenarios as discussed below are examined. The maximum storage is assumed as 53 million m^3 in all scenarios.

3.2.1. Scenario 1: Reduced irrigation water demand

The downstream land is being rapidly converted to residential areas. This has resulted in decreased crop area for irrigation. Although there has not been any study to find the reduction in irrigation land, the land around the left bank canal is more vulnerable to such a reduction. This will reduce irrigation water demand as well. Therefore, simulation is developed to examine the water requirement for irrigation with a reduction in 50% of the irrigable land in the command area. The analysis presented in Fig. 5 shows that as the water requirement for irrigation is much less than that required for power generation, it would not have substantial impact to resolve water use conflict. Therefore, scenarios with different hydropower generation capacity are examined next.

3.2.2. Scenario 2a: Continuous power generation

Another scenario is examined to provide irrigation water throughout the year but providing water for power generation at full capacity during the wet season and at half capacity during the dry season. As the station is linked up to national grid, such an operation policy is feasible. Simulation shows power can be generated at full capacity from June to November and at half capacity for the rest of the months without creating water use conflicts. The simulation result (Fig. 5) shows that with this operation policy, power

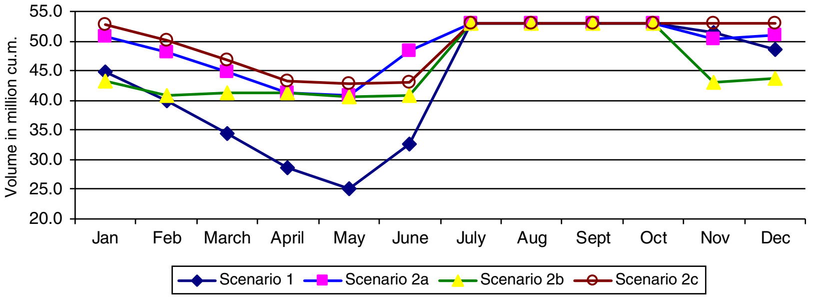

Fig. 5. Simulation result for dam operation with different power station operating policy.

generation can be increased to 5.9 GWh, which is more than 25% improvement over the current operation policy.

3.2.3. Scenario 2b: Capacity upgrade and continuous power generation

As an important objective of the power plant is to generate electricity to upload to the national grid, an upgrading of the power system to 2 MW is considered. This upgrading is technically feasible because the power canal system infrastructure is already there. The turbines and penstock pipes have to be replaced with new turbines and the penstock pipes. Although assumed hypothetically here, this scenario is not entirely impossible as the Nepal Electricity Authority, which owns the power station is coining the idea of handing this power station over to private entrepreneurs on a long-term lease. In such a case, the lessee can upgrade the capacity of turbines and opt for a different operating policy. As water is sufficient during the rainy periods, the lessee can operate the power station at full capacity (2 MW) in those months. The two situations were examined under this scenario. The first situation is to generate power at full capacity (2 MW) from June to November and at 25% (500 kW) from December to February and in May. For the remaining period, the generating station is shut down. This option generates more power and does not create any water use conflict. Fig. 5 (scenario 2b) shows that water level at the dam can be maintained with this operating policy. The annual power generation with this policy would be 8.1 GWh. However, this situation is similar to the current policy, as the power generation has to be stopped for 4 months.

Another situation is to choose an operation policy that allows operation of power station throughout the year (even if at a lower capacity). Simulation indicates that if power generation is at 2 MW capacity from June to October, at 1 MW capacity for November and at 500 kW capacity for the rest of the periods, then it would not create any water use conflict. This policy would also generate 8.1 GWh of electricity and would allow hydropower generation continuously. This might be a better solution compared to the first situation, as the lessee might be able to maintain the workforce due to continuous operation of the system.

3.2.4. Scenario 2c: Peak power generation

Nepal's current electricity demand structure shows that the system peaks for about 6 h in the evening (http://nea.org.np/newtariffrate.htm), mainly due to higher share of consumption in the residential sector. This peak demand is currently managed through

blackouts. Since electricity demand is increasing due to continuous expansion of the transmission and distribution systems, any contribution to peak load would be a welcome. As restructuring of tariff for peak power is being considered by the Electricity Authority, adoption of this option could bring additional revenues to the hydropower station as well. In the light of the above, another option for the hydropower is examined with 2 MW upgrade. From simulation (shown in Fig. 5), it is found that the other non-conflict water use would be to run the turbine at full capacity throughout the day from June to October and then at full capacity for 6 h in the evening for all other months. This operation policy will generate 7.9 GWh of electricity but hopefully it might fetch more income compared to scenario 2b mentioned above. This situation could be of special importance to rural stand-alone power generating station where electricity demand is generally dominated by the residential sector.

3.3. Scenarios with normal operating level

As a comparison, all four scenarios mentioned above were examined by assuming normal poundage level of 45.6 million m^3. The resulting graph in Fig. 6 shows that none of the operation policy becomes viable under this assumption. From this, it can be concluded that a higher poundage level with adoption of a different operating policy can avoid water use conflicts in the study area. Although power generation could have been made continuous by generating full capacity (1 MW) for about 4–5 months and at half the capacity for the rest of the period, this will decrease power generation and potential income from the same resource.

3.4. Discussion and conclusions

The reservoir has the utmost preference for recreational purposes. However, recreational purpose is not hampered even if the water in the reservoir goes down to dead storage level. The downstream use of this stored water for irrigation and power generation is of main concern as substantial investments have been made to build the respective infrastructure. Such investments are irreversible and it is only in the best interest of the planners to make the use of the investment for highest return. Therefore, the examination of water use for both irrigation and hydropower generation, given different operation policy makes this study a unique contribution to the analysis of water use conflict in post-project situations.

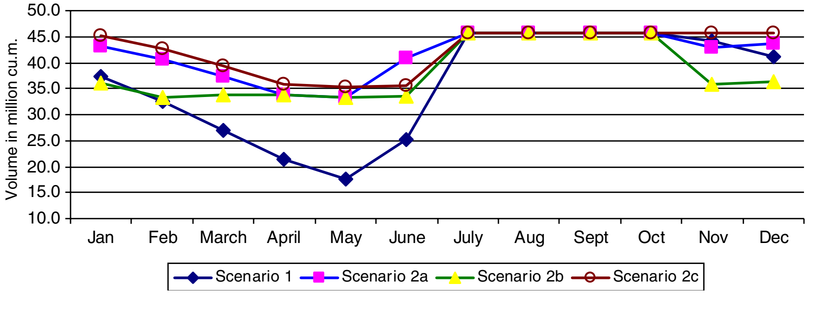

Fig. 6. Simulation result for dam operation at average poundage level.

The project clearly shows that downstream water use conflict has arisen because of water requirements for hydropower generation. When hydropower project was commissioned the objective was to replace the diesel-fueled electricity generator that was supplying electricity in the study area only for few hours a day. This short-term target was fulfilled when the generation station was completed. However, this station could not sustain the ever-increasing electricity demand. Further, the extension of national grid for electricity supply made this power plant defunct for a number of years. Moreover, with increasing power shortages and impetus to handover small-scale hydropower generation units to the private sector, the revival of this power station has come to the forefront again. However, study as to the viability of the power station as a business venture has not been made. The lacking part was the standing old turbines and the perception of lack of water for generation. This study is contributive to the second aspect as it is clearly seen that even with upgrades in the capacity of the system, which is technically feasible, the hydropower station can generate more power without affecting irrigation water demand. As the power plant had been shut down for nearly 3 years due to non-ending water use conflicts and has operated only at about 25–40% capacity for some months of the year, an analysis of water use conflict was warranted to gain insights.

The handing over of power generation plant on long-term lease to private sector could be a better option to the fund crunched electricity authority. Pokharel [8] has mentioned that when such small loss making hydropower stations were leased, private entrepreneurs were able to manage the projects properly to generate substantial profits. Therefore, if an option for upgrading and power purchase agreement is made available to the lessee, the option would be more attractive. With the Local Development Act (providing local jurisdiction over resource use) in place, the dam regulator (in this case the local irrigation office) or the district development office can also generate extra revenues from water provided to hydropower generation. This will become a win–win situation for the parties involved and would also avoid water use conflict in the long run. With increasing use of crop land for residential and commercial purposes in the study area, it is only natural to assume that a suitably designed and operated hydropower station can be economically viable in the watershed.

If water level could be maintained at 795.7 m (flood levels) the dam would store about 6 million m^3 more water. This would meet the current water demand for recreation, irrigation and power generation throughout the year without creating any water use conflict. This option is not technically infeasible at the dam site, unless the department of irrigation is taking extreme precaution to avoid another catastrophe of dam failure. Also, it would not require additional submergence of peripheral lands beyond the flood water levels.

It is therefore, suggested that when dams are constructed in small watershed like that studied here, the policy planners should provide value adding services to the existing water usages, that is, to provide additional usage of water for the benefit of local people in the long term. The following options are recommended based on the study.

- Increasing the capacity of power station to a higher level and to generate power to full capacity during the rainy season. As Nepal does not yet have sufficient electricity generation to meet its demand and since the electricity demand is increasing due to the extension of transmission and distribution system, any addition to generation capacity would be a contribution to augmenting electricity supply.

- As the water use conflict in the study area is brought about by the water use for hydropower generation, the current power generation policy has to be changed to suit water availability, that is, to run at maximum capacity during the rainy season and to run at a lower capacity throughout the remaining months. This way the water supply option for recreation, irrigation and power generation become continuous and sustainable.
- For a more sustainable water supply to meet all three uses of water in the study area, it is advised that normal water level be increased to 795.7 m. This will retain more flood water and would be a better option for dam water regulation.
- Another option would be to raise the capacity of power station and to generate only peak power throughout the year. This will help in shedding at least some stress off the peak power demand.

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Shaligram Pokharel is an Associate Professor at the School of Mechanical and Aerospace Engineering at the Nanyang Technological University. Before joining the university in June 2000, he worked as an Energy Planner at the Water and Energy Commission Secretariat (WECS), Singha Darbar, Kathmandu, Nepal and was responsible for major works done by WECS on energy sector. Among his important works were the development of energy balance sheets for Nepal for the first time, drafting the first comprehensive renewable energy policy for adoption

by the National Planning Commission for Nepal, commissioning Energy Sector Synopsis study for Nepal, coordinating the study on agriculture sector energy consumption, district energy profiles for Nepal and the impact of solar PV for rural irrigation. His current works are in the area of industrial management and energy. Dr. Pokharel has obtained his Mechanical Engineering from the University of Kashmir, India and M.Sc. and Ph.D. in Systems Design Engineering from the University of Waterloo, Canada.